C++ Constructor Insanity (part 1)

CSE 333 Spring 2023

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Relevant Course Information

- Exercise 6 released today, due next Monday (4/24)
  - Write a substantive class in C++ (uses a lot of what we will talk about in lecture today)
  - Testable material on midterm, but will count as a "bonus" w.r.t. exercise grading

- Homework 2 due next Thursday (4/27)
  - File system crawler, indexer, and search engine
  - Note: `libhw1.a` (yours or ours) and the `.h` files from hw1 need to be in right directory (`~yourgit/hw1/`)
  - Note: use Ctrl-D to exit `searchshell`
  - Tip: test on directory of small self-made files
  - Partner confirmation by *4/20 @ 11:59 PST;* No exceptions!

Lecture Outline (cont'd from last lecture)

- **C++ Classes Intro**

Classes

- Class definition syntax (in a `.h` file):

```
class Name {
 public:
  // public member definitions & declarations go here

 private:
  // private member definitions & declarations go here
};  // class Name
```

don't forget!

  - Members can be functions (methods) or data (variables)

- Class member function definition syntax (in a `.cc` file):

```
retType Name::MethodName(type1 param1, …, typeN paramN) {
  // body statements
}
```

  - (1) *define* within the class definition or (2) *declare* within the class definition and then *define* elsewhere

Class Organization

- It's a little more complex than in C when modularizing with `struct` definition:
  - Class definition is part of interface and should go in `.h` file
    - Private members still must be included in definition (!)
  - Usually put member function definitions into companion `.cc` file with implementation details
    - Common exception: setter and getter methods
  - These files can also include non-member functions that use the class

- Unlike Java, you can name files anything you want
  - Typically `Name.cc` and `Name.h` for `class Name`

Const & Classes

- Like other data types, **objects** can be declared as `const`:
  - Once a `const` object has been constructed, its member variables can't be changed
  - Can only invoke member functions that are labeled `const`
- You can declare a member **function** of a class as `const`
  - This means that it cannot modify the object it was called on
    - The compiler will treat member variables as `const` inside the function at compile time
  - If a member function doesn't modify the object, mark it `const`!

Class Definition (.h file)

Point.h

```
#ifndef POINT_H_
#define POINT_H_

class Point {
 public:
  Point(const int x, const int y);                       // constructor
  int get_x() const { return x_; }                        // inline member function
  int get_y() const { return y_; }                        // inline member function
  double Distance(const Point& p) const;                  // member function
  void SetLocation(const int x, const int y);             // member function

 private:
  int x_;  // data member
  int y_;  // data member
};  // class Point

#endif  // POINT_H_
```

this const means that this function is not allowed to change the object on which it is called (the implicit "this" pointer)

function definitions

declarations

compiler may choose to expand inline (like a macro) instead on an actual function call

naming convention for class data members (Google C++ style guide)

Class Member Definitions (.cc file)

Point.cc

```
#include <cmath>
#include "Point.h"

Point::Point(const int x, const int y) {
  x_ = x;
  this->y_ = y;  // "this->" is optional unless name conflicts
}

double Point::Distance(const Point& p) const {
  // We can access p's x_ and y_ variables either through the
  // get_x(), get_y() accessor functions or the x_, y_ private
  // member variables directly, since we're in a member
  // function of the same class.
  double distance = (x_ - p.get_x()) * (x_ - p.get_x());
  distance += (y_ - p.y_) * (y_ - p.y_);
  return sqrt(distance);
}

void Point::SetLocation(const int x, const int y) {
  x_ = x;
  y_ = y;
}
```

Handwritten annotations:
- BAD STYLE used here on purpose
- equivalent to y_ = y;
- "this" is a (Point * const)
- makes "this" a (const Point * const)
- equivalent to p.x_
- can't be const because we are mutating "this"

Class Usage (.cc file)

usepoint.cc

```
#include <iostream>
#include <cstdlib>
#include "Point.h"

using namespace std;

int main(int argc, char** argv) {
  Point p1(1, 2);  // allocate a new Point on the Stack
  Point p2(4, 6);  // allocate a new Point on the Stack

  cout << "p1 is: (" << p1.get_x() << ", ";
  cout << p1.get_y() << ")" << endl;

  cout << "p2 is: (" << p2.get_x() << ", ";
  cout << p2.get_y() << ")" << endl;

  cout << "dist : " << p1.Distance(p2) << endl;
  return EXIT_SUCCESS;
}
```

calls defined constructor

"dot notation" used for member functions

Reading Assignment

- ***Read*** the sections in *C++ Primer* covering class constructors, copy constructors, assignment (`operator=`), and destructors
  - Ignore "move semantics" for now
  - The table of contents and index are your friends…

struct vs. class

- In C, a `struct` can only contain data fields
  - No methods and all fields are always accessible
- In C++, `struct` and `class` are (nearly) the same!
  - Both can have methods and member visibility (public/private/protected)
  - Minor difference: members are default *public* in a `struct` and default *private* in a `class`
- Common style convention:
  - Use `struct` for simple bundles of data ← public data members with names like x, y
  - Use `class` for abstractions with data + functions ← private data members with names like x_, y_

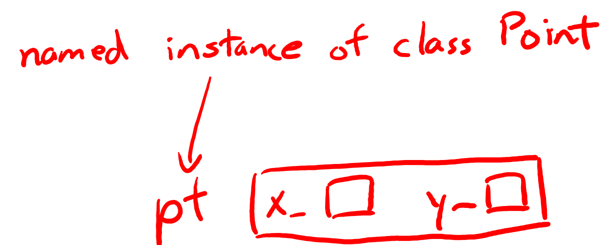
Memory Diagrams for Objects

- An **object** is an instance of a class that maintains its *state* independent from other objects
  - This state is the collection of its data members
  - Conceptually, an object acts like a collection of data fields (plus class metadata)
    - Layout is *not* specified or guaranteed, unlike structs in C

- Drawn out as variables within variables:

```
class Point {
  ...

 private:
  int x_;   // data member
  int y_;   // data member
};  // class Point
```



Lecture Outline

- **Constructors**
- Copy Constructors
- Assignment (next lecture)
- Destructors (next lecture)

Constructors

- A constructor (ctor) initializes a newly-instantiated object
  - A class can have multiple constructors that differ in parameters
  - A constructor *must* be invoked when creating a new instance of an object – which one depends on *how* the object is instantiated

- Written with the class name as the method name:

```
Point(const int x, const int y);
```

  - C++ will automatically create a synthesized default constructor if you have *no* user-defined constructors
    - Takes no arguments and calls the default ctor on all non-"plain old data" (non-POD) member variables
    - Synthesized default ctor will fail if you have non-initialized const or reference data members

created for you zero-argument

Synthesized Default Constructor Example

```
class SimplePoint {
 public:
  // no constructors declared!
  int get_x() const { return x_; }      // inline member function
  int get_y() const { return y_; }      // inline member function
  double Distance(const SimplePoint& p) const;
  void SetLocation(int x, int y);

 private:
  int x_;  // data member
  int y_;  // data member
};  // class SimplePoint
```

default behavior → primitives: just allocate space (mystery data)
→ objects: default construct

SimplePoint.h

```
#include "SimplePoint.h"

... // definitions for Distance() and SetLocation()

int main(int argc, char** argv) {
  SimplePoint x;  // invokes synthesized default constructor
  return EXIT_SUCCESS;
}
```

(main) x | x_ ? y_ ? |

SimplePoint.cc

Synthesized Default Constructor

- If you define *any* constructors, C++ assumes you have defined all the ones you intend to be available and will *not* add any others

```
#include "SimplePoint.h"

// defining a constructor with two arguments
SimplePoint::SimplePoint(const int x, const int y) {
  x_ = x;
  y_ = y;
}

void Foo() {
  SimplePoint x;        // compiler error:  if you define any
                        // ctors, C++ will NOT synthesize a
                        // default constructor for you.

  SimplePoint y(1, 2);  // works:  invokes the 2-int-arguments
                        // constructor
}
```

added, so no synthesized def ctor

Multiple Constructors (overloading)

```
#include "SimplePoint.h"

// default constructor
SimplePoint::SimplePoint() {
  x_ = 0;
  y_ = 0;
}

// constructor with two arguments
SimplePoint::SimplePoint(const int x, const int y) {
  x_ = x;
  y_ = y;
}

void Foo() {
  SimplePoint x;          // invokes the default constructor
  SimplePoint y(1, 2);    // invokes the 2-int-arguments ctor
  SimplePoint a[3];       // invokes the default ctor 3 times
}
```

added, so now there is a def. ctor

int : a | ? | ? | ? |

SimplePoint : a | x_ 0 y_ 0 | x_ 0 y_ 0 | x_ 0 y_ 0 |

Initialization Lists

- C++ lets you *optionally* declare an initialization list as part of a constructor definition
  - Initializes fields according to parameters in the list
  - The following two are (nearly) identical:

```
Point::Point(const int x, const int y) {
  x_ = x;
  y_ = y;
  std::cout << "Point constructed: (" << x_ << ",";
  std::cout << y_<< ")" << std::endl;
}
```

```
// constructor with an initialization list
Point::Point(const int x, const int y) : x_(x), y_(y) {
  std::cout << "Point constructed: (" << x_ << ",";
  std::cout << y_<< ")" << std::endl;
}
```

can be expressions

member names

body can be empty { }

Initialization vs. Construction

```
class Point3D {
 public:
  // constructor with 3 int arguments
  Point3D(const int x, const int y, const int z) : y_(y), x_(x) {
    z_ = z;
  }

 private:
  int x_, y_, z_;  // data members
};  // class Point3D
```

First, initialization list is applied.

Next, constructor body is executed.

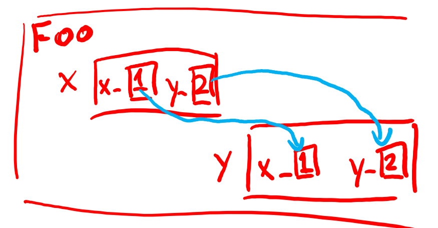
- Data members in initializer list are initialized in the order they are defined in the class, not by the initialization list ordering (**!**)
  - Data members that don't appear in the initialization list are *default initialized/constructed* before body is executed

- Initialization preferred to assignment to avoid extra steps
  - Real code should never mix the two styles

Lecture Outline

- Constructors
- **Copy Constructors**
- Assignment (next lecture)
- Destructors (next lecture)

Copy Constructors



- C++ has the notion of a copy constructor (cctor)
  - Used to create a new object as a copy of an existing object

```
Point::Point(const int x, const int y) : x_(x), y_(y) { }

// copy constructor
Point::Point(const Point& copyme) {
  x_ = copyme.x_;
  y_ = copyme.y_;
}

void Foo() {
  Point x(1, 2);  // invokes the 2-int-arguments constructor

  Point y(x);     // invokes the copy constructor
                  // could also be written as "Point y = x;"
}
```

reference to object of same class

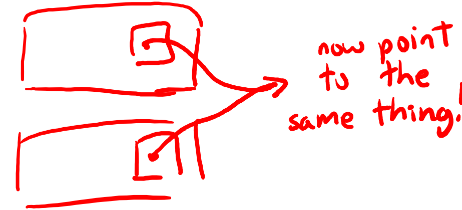
alias binds to object

constructing from existing object, so we use the copy ctor.

a ctor must be called because the object didn't exist previously.

  - Initializer lists can also be used in copy constructors (preferred)

Synthesized Copy Constructor



- If you don't define your own copy constructor, C++ will synthesize one for you
  - It will do a *shallow* copy of all of the fields (*i.e.*, member variables) of your class (can be problematic with pointers)
  - Sometimes the right thing; sometimes the wrong thing

```
#include "SimplePoint.h"

... // definitions for Distance() and SetLocation()

int main(int argc, char** argv) {
  SimplePoint x;
  SimplePoint y(x);   // invokes synthesized copy constructor
  ...
  return EXIT_SUCCESS;
}
```

When Do Copies Happen?

- The copy constructor is invoked if:
  - You *initialize* an object from another object of the same type:

```
Point x;         // default ctor
Point y(x);      // copy ctor
Point z = y;     // copy ctor
```

  - You pass a non-reference object as a value parameter to a function:

```
void Foo(Point x) { ... }

Point y;         // default ctor
Foo(y);          // copy ctor
```

pass-by-value of an object

  - You return a non-reference object value from a function:

```
Point Foo() {
  Point y;       // default ctor
  return y;      // copy ctor
}
```

Compiler Optimization

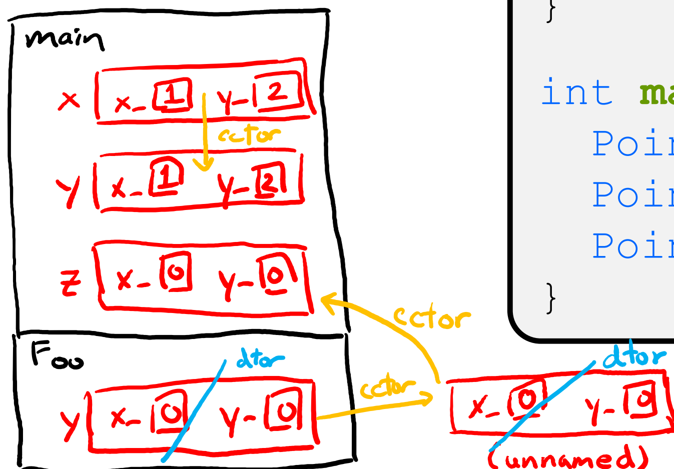
- The compiler sometimes uses a "return by value optimization" or "move semantics" to eliminate unnecessary copies
  - Sometimes you might not see a constructor get invoked when you might expect it

(unnamed temporary object)

↑ can read up on your own if interested

```
Point Foo() {
  Point y;          // default ctor
  return y;         // copy ctor? optimized?
}

int main(int argc, char** argv) {
  Point x(1, 2);    // two-ints-argument ctor
  Point y = x;      // copy ctor
  Point z = Foo();  // copy ctor? optimized?
}
```



Extra Exercise #1

- Write a C++ program that:
  - Has a class representing a 3-dimensional point
  - Has the following methods:
    - Return the inner product of two 3D points
    - Return the distance between two 3D points
    - Accessors and mutators for the `x`, `y`, and `z` coordinates

Extra Exercise #2

- Write a C++ program that:
  - Has a class representing a 3-dimensional box
    - Use your Extra Exercise #1 class to store the coordinates of the vertices that define the box
    - Assume the box has right-angles only and its faces are parallel to the axes, so you only need 2 vertices to define it
  - Has the following methods:
    - Test if one box is inside another box
    - Return the volume of a box
    - Handles <<, =, and a copy constructor
    - Uses `const` in all the right places